THE ENHANCEMENT OF EMISSIONS EFFICIENCY THROUGH UTILIZATION OF VEHICLE TO GRID TECHNOLOGY

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ii. Executive Summary

Electric vehicles with large capacity batteries are capable of providing benefits to the electric grid itself like load shifting and even potential exporting of power. More interestingly, vehicles are parked 90% of the time (LeTendre & Denholm, 2006), and therefore can be expected to be in a specific location at a specific time and provide exact capacity export, something renewables cannot do.

This research is predicated on a forecasting model that considers two main scenarios. The objective of the model was to recreate a national perspective that could estimate time-of-use and grid emissions on an hourly basis. The resulting values demonstrate significant emissions savings on an hourly basis created by consideration of time of use charging and vehicle-to-grid exporting of power.

The vehicle-to-grid scenario provides substantial improvements by flattening the demand and shifting power from peak times to off-peak times. The vehicle-to-grid scenario results in notable emissions savings when considering the overall load increases by 22.38% in 2050 but the total emissions from the grid only increases by 12.79% at that time. The grid emissions efficiency is realized by a conversion of peaking, single cycle natural gas turbine power facilities to a more efficient combined cycle, base load technology.

As the load increases and flattens out, inefficient peaking technologies are no longer needed. In addition, these peaking technologies are replaced by battery storage that loads up during off peak hours, further improving efficiencies. The change from peaking to base load natural gas power supply can be seen in *Table 7 Base Load NG Supply* and *Table 8 Peaking Natural Gas Supply* located in *Appendix B – Additional* Tables.

This study further solidifies the notion that not only do electric vehicles provide emissions savings on a simple comparison to gasoline vehicles but they provide efficiency improvements to the grid itself that creates further emissions savings. With the expected growth in renewable capacity and need for storage, electric vehicles can provide the solution while savings more emissions.

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Section 1 - Introduction

In 2016, the transportation sector eclipsed the electric power market in total carbon dioxide emissions. Furthermore, the EIA projects this trend to continue all the way through 2040 (EIA, 2017). In the US, the generation of electricity accounts for 35% of greenhouse gas emissions. Meanwhile, the transportation sector is accounts for 36%. These industries are the top two emissions sources in the country, responsible for well over half of all the US based greenhouse gas emissions. In the transportation sector, 41% of all emissions are related to light vehicles which are the number one contributor of emissions from the sector, and therefore account for approximately 15% of all US emissions (EIA, 2017). This is due to nearly all passenger vehicles running on gasoline.

When searching for a solution to address a new and significant problem, one must focus on answers that are economical to be quickly adopted. In terms of types of resources to solve such a problem, the resources must be inexpensive and readily available. As electric vehicle technology continues to break through previous limitations in both capacity and cost, a new, cost effective and readily available resource will become widely distributed throughout the country.

Electric vehicles with large capacity batteries are capable of providing benefits to the electric grid itself like load shifting and even potential exporting of power. More interestingly, vehicles are parked 90% of the time (LeTendre & Denholm, 2006), and therefore can be expected to be in a specific location at a specific time and provide exact capacity export, something renewables cannot do.

In addition, the electric market is constantly changing and with the projected expansion of intermittent renewable generation assets, the expected need for storage capacity will continue to grow to support continuous and safe delivery of electricity. Expansion of electric vehicles can play a major role in not just providing a more secure power source, but have the benefit of reducing emissions both from the grid and from replacement of gasoline power vehicles.

The purpose of this research paper and complementary model is to identify the true emissions savings from a full electric vehicle compared to gasoline fueled vehicles now and in the future. The benefits of electric vehicles can be larger than anticipated, and, as an ancillary benefit, improve the overall efficiency of both the electric and transportation sectors.

It is anticipated that benefits to utilities by deploying electric vehicles include an increased load factor (average demand divided by peak demand) and reduced cycling of facilities (LeTendre & Denholm, 2006). These improvements to the generation supply should also reduce emissions by the grid on a per unit of electricity basis by improving overall efficiency of operations. Therefore, when considering time of use and vehicle-to-grid in the emissions portfolio of an electric vehicle, electric vehicle net emissions should be reduced even further as well as the overall emissions efficiency of the electric generation itself will show improvement.

The model created considers two main scenarios that are further explained below. It is important to note that one scenario considers "vehicle-to-grid" technology, the idea that high capacity car batteries can act as distributed energy resources. Vehicle-to-grid in this model is assumed as a pure net metering opportunity. Many studies believe that the best aspects of vehicle-to-grid are actually in the ancillary electric markets like frequency regulation and demand response. However, due to differences in interstate system operators across the country of which the treatment of these benefits is not uniform, no ancillary markets are considered.

Section 2 - Methods

The objective of the model was to recreate a national perspective that could estimate time-of-use and emissions on an hourly basis. This required two priority considerations: creating a national daily demand curve and a national daily dispatch model. By completing these priorities, an effective model could be created to estimate hourly emissions more accurately to consider when an electric vehicle is charging or dispatching power in a V2G scenario.

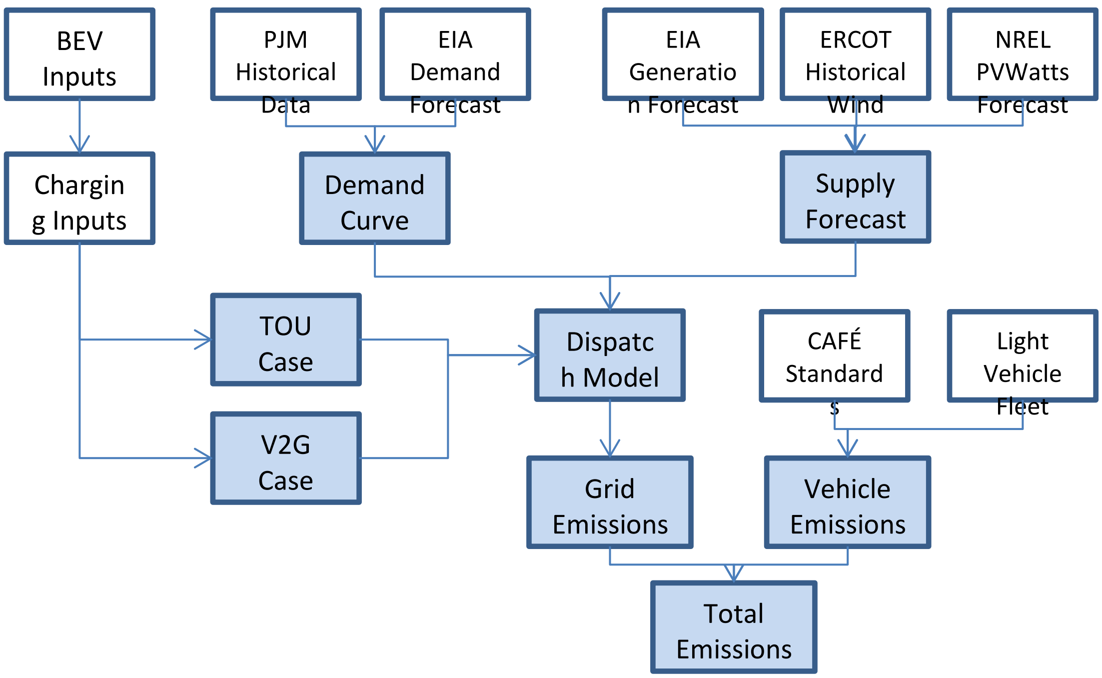
To create a demand curve, the PJM ISO is assumed as the national standard for demand shape. By taking five years of hourly historical data from 2012 through and including 2016, the average load per hour over 5 years was calculated. The average load per hour was then divided by the entire average daily load to create a percentage of load for the day in any given hour. This demand distribution creates a demand shape that can be reutilized for a national scale. This shape can be seen in *Table 5. PJM Load Distribution* in *Appendix B* – Additional Tables.

The EIA's 2017 Annual Energy Outlook ("AEO") forecasts national demand on an annual basis out to 2050. The annual demand can then be put into the PJM demand distribution to create a daily demand curve of national energy use. In the model, the demand actually demonstrates the total billion kWh utilized in a specific hour of the day throughout the entire year, so that if the 24 hours of the day are aggregated, it would equal to total national annual demand in billion kWh. This creates a shape and a curve that can be filled in with the available generation options with annual data from the AEO to demonstrate what generation technology is employed and when.

As previously mentioned, the AEO includes annual generation projections by generation technology out to 2050. Therefore, utilizing certain dispatch rules outlined in the *Appendix A – Assumptions*, a dispatch curve was created that prioritized renewables, base load technologies, and peaking technologies, in that order. With this dispatch model, one can estimate the emissions in CO2 equivalent per kWh in any given hour on a national scale. An example if the dispatch model can be found in *Appendix B* – Additional Tables demonstrating the EIA Reference Case for 2020 (*Table 6. 2020 Base Case Dispatch Model*).

Figure 1 Research Methodology Flow Chart

The diagram below outlines the data analyzed to create the final emissions projections.



After the demand curve and dispatch model are created, assumptions can be made on when an electric vehicle is charged and provide a more accurate estimate of the emissions tied to the electricity consumed during that time. The expected result should be more accurate than a national emission per kWh average that does not consider time of use. The Time of Use Scenario ("TOU Scenario") estimates the emissions savings by converting gasoline vehicles to electric vehicles and the emissions from the power charging the electric vehicle from the generation technologies dispatched during the time the battery is charged. The Vehicle-to-Grid Scenario ("V2G Scenario) takes this model iteration further. The V2G scenario considers the emissions per kWh during the charging as well as the emissions per kWh of the power it replaces when the battery in the electric vehicle is dispatching power to the electric grid.

To calculate the emissions savings, there are multiple ways to interpret the data. First, an estimate is created to calculate the emissions in the grid itself as the dispatched technologies change according to demand and load shape to support expansion of electric vehicles. This can be added to a transportation emissions savings estimate by converting gasoline vehicles to non-emitting electric vehicles to create a total emissions savings value. Second, a per vehicle emissions calculation is created to estimate the impact on a smaller scale of converting a gasoline vehicle to an electric vehicle in both the TOU and V2G Scenarios compared to a base BEV scenario that does not consider TOU or V2G, but an average grid emissions in total.

Section 3 - Results

The following is a summary of the demand curves and dispatch models for all three scenarios: Base Case, TOU Case and V2G Case. The emissions results are summarized at the end of the section. Each case is projected for snapshots in 2020, 2030, 2040 and 2050. Please see the *Appendix A – Assumptions* to review what is assumed to build out the projected dispatch models.

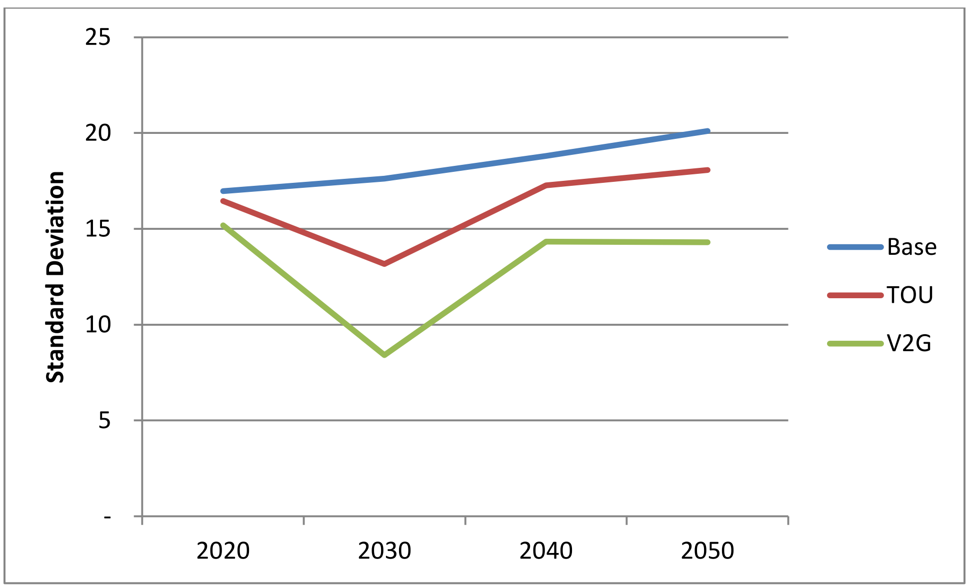
3.1 Demand Volatility

To calculate volatility, a standard deviation was taken of each scenario demand forecast for a given year. The standard deviation allows the measurement of volatility by quantifying the variation among the values. The lower a standard deviation is indicates less variation in values. It would be assumed that lower standard deviations align with less volatility and better emissions efficiency. As shown in the table and chart below, both the TOU and V2G cases improve demand volatility by lowering the standard deviation of the demand.

Table 1 Standard Deviation of Demand

Standard Deviation of Demand	***Base***	***TOU***	***V2G***
2020	16.97	16.45	15.18
2030	17.62	13.17	8.41
2040	18.81	17.26	14.33
2050	20.11	18.06	14.30

Figure 2 Demand Volatility

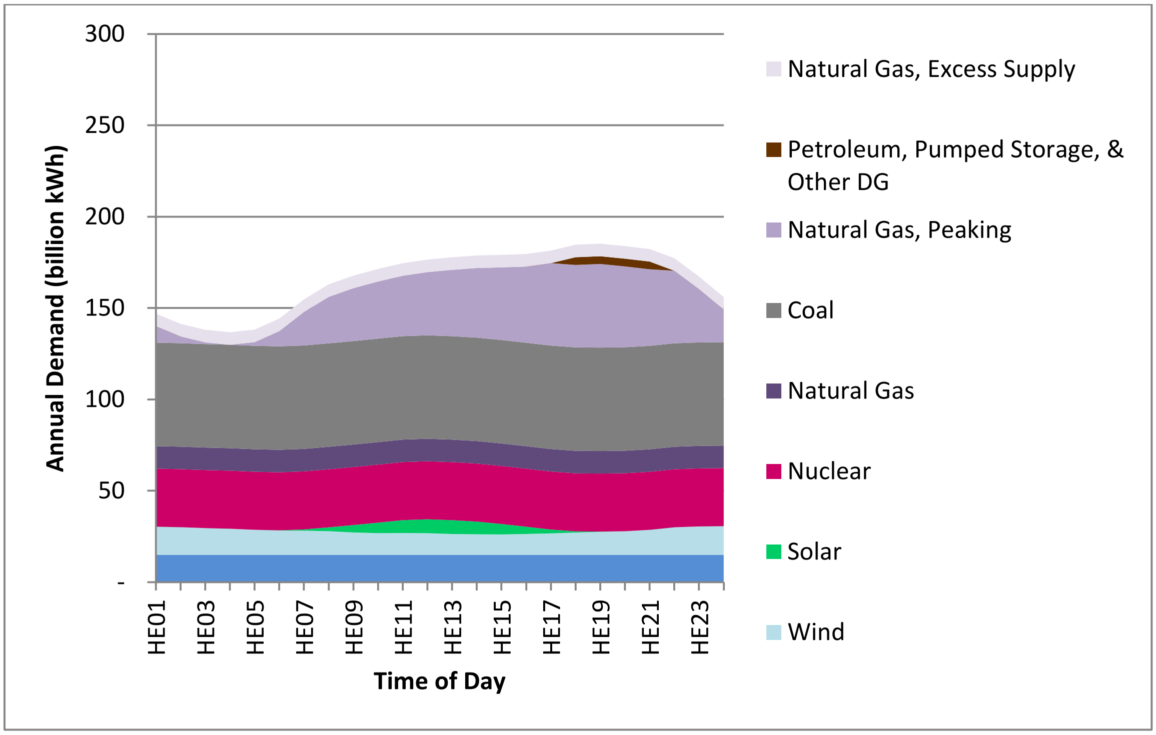


Interestingly, the lowest volatility values are seen in 2030 for the TOU and V2G cases, where 9% of all light vehicles are BEV that charge in the morning. It is clear that reductions in volatility do not have a perfect correlation to emissions efficiency, but in every timeframe, TOU and V2G have less volatility than the Base Case.

3.2 Base Case

The Base Case assumes EIA projections on both generation resources and total demand while utilizing the PJM demand curve shape.

Figure 3 Base Case 2020

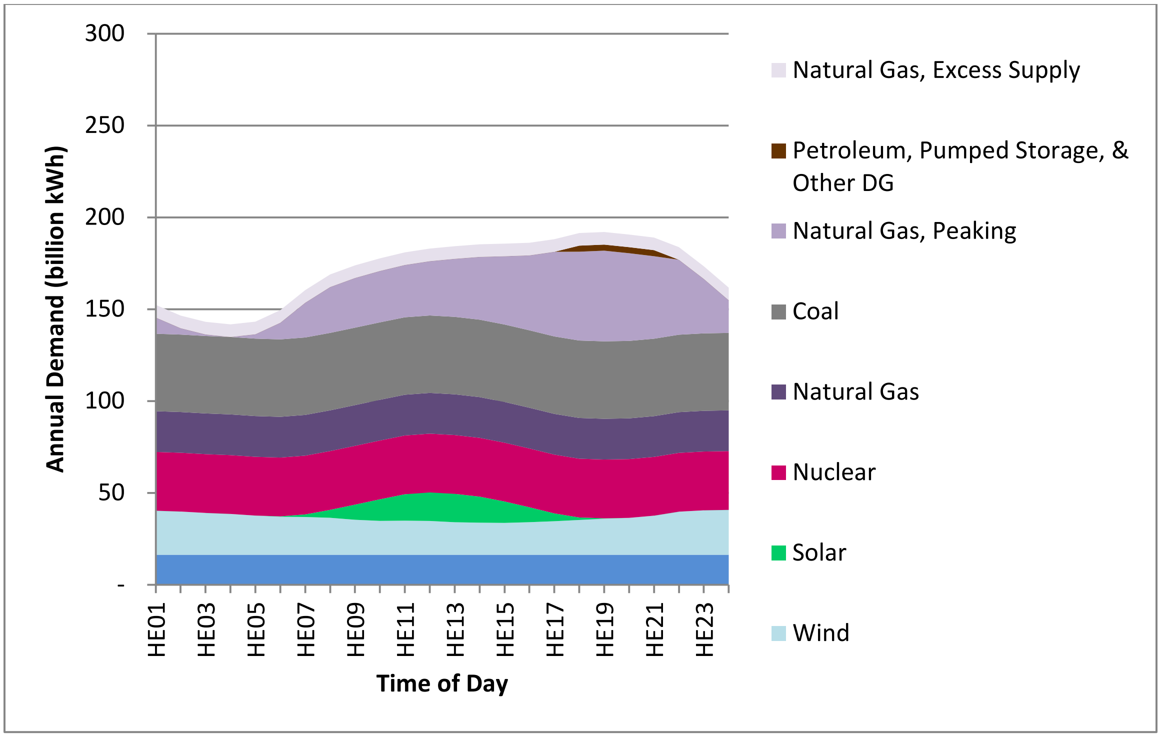


The Base Case 2020 is a great reference case that is closest to the current energy environment. It's easy to see that both coal and nuclear are large parts of the dispatch model. Additionally, natural gas generation comes mostly in the form of peaking natural gas, a less efficient application. Solar, wind and other renewables are all prioritized in dispatch due to their intermittent nature.

This shape shows a true on and off peak model with inefficient technologies like single cycle natural gas, petroleum and pumped storage meeting the peak demand hours of the day.

The average CO2e emissions are 419 g/kWh. The top power producing resource is coal.

Figure 4 Base Case - 2030

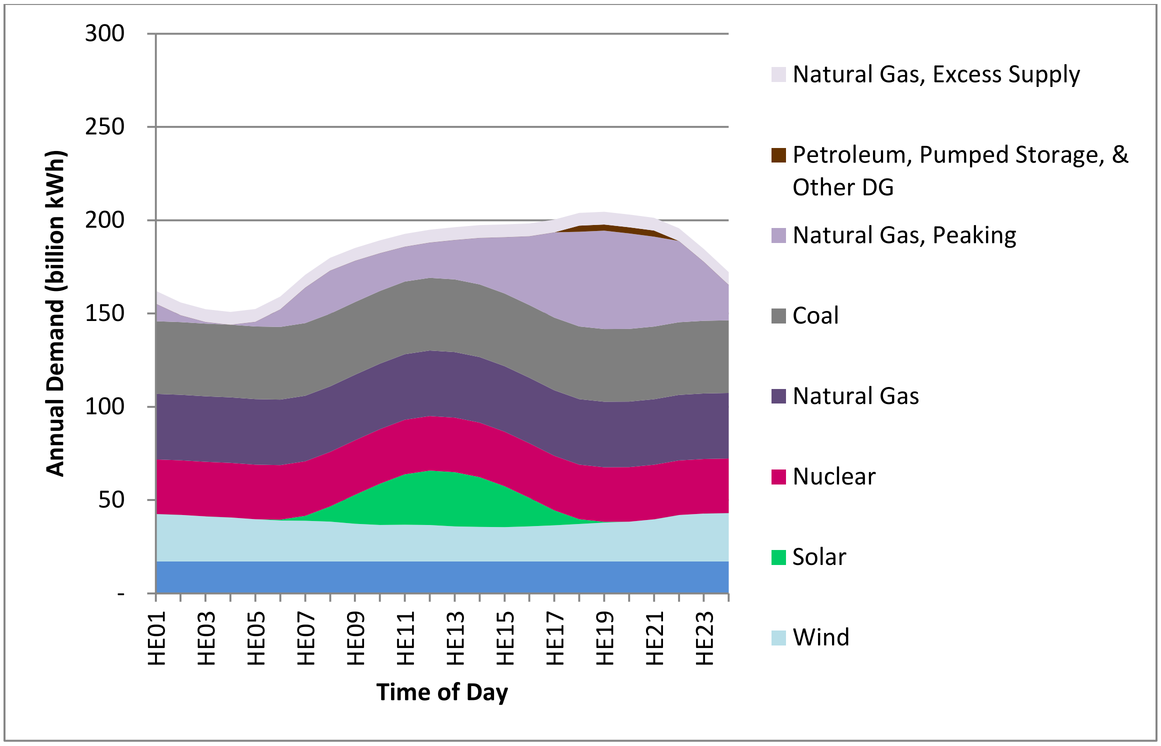


The Base Case 2030 begins to demonstrate the impact of renewable expansion. Wind growth generally pushes the entire curve upward, but solar creates a mid-day "hump" in the dispatch model. This "hump" can cause inefficiency in the natural gas generation dispatch, as more peaking natural gas will be required once the sun goes down on the solar arrays, an issue currently experience in CAISO commonly referred to as the "Duck Curve" (CAISO, 2016).

As demand grows, base load natural gas capacity has improved from 26% to 40% of all natural gas generation. This creates a more emissions efficiency in the dispatch model.

The average CO2e emissions are 354 g/kWh. The top power producing resource is coal.

Figure 5 Base Case - 2040



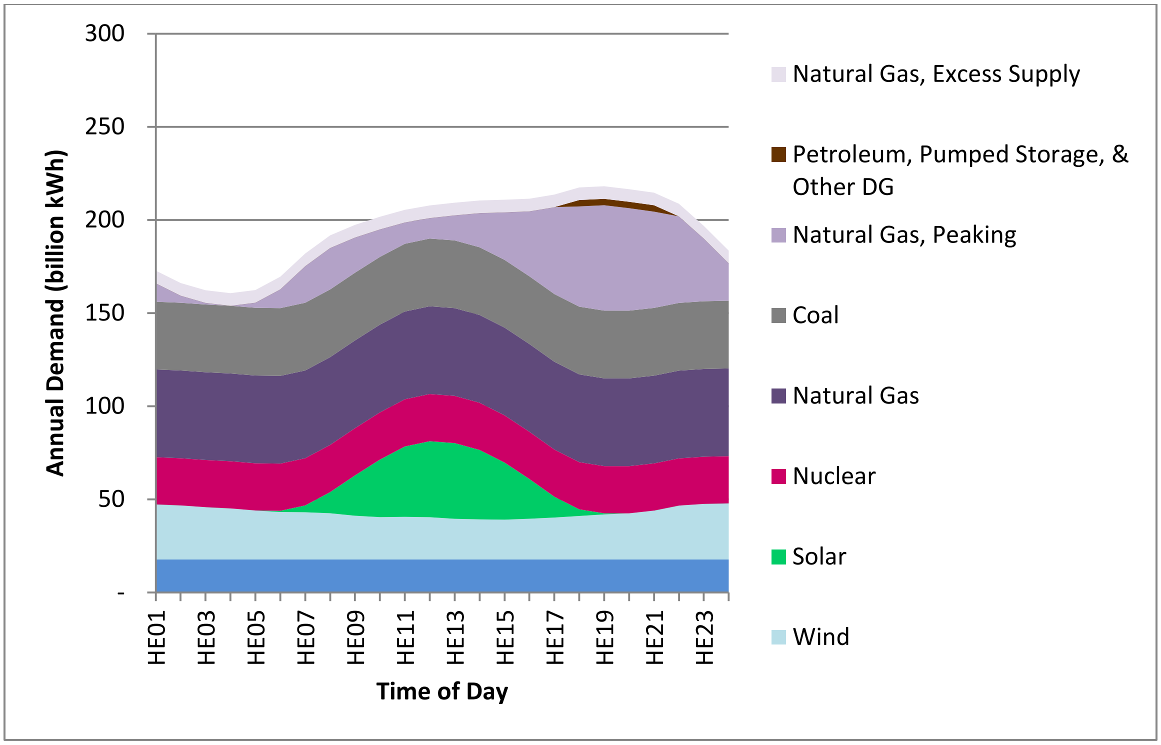
The Base Case 2040 shows the electric market to continue to shift to renewables and base load natural gas generation. Renewables in this scenario account for 27% of all generation across the U.S. and the combined natural gas technologies account for 38% of all generation.

Of the natural gas generation, over 52% will be base load generation by 2040. The increasing renewables and base load natural gas create greater emissions efficiencies.

When considering nuclear and all renewables, over 43% of all power in 2040 will have zero emissions. Coal and petroleum based supply capacity has declined over the decade, as per 2030 vs 2020, and will continue to do so through 2050.

The average CO2e emissions are 340 g/kWh. The top power producing resource is coal.

Figure 6 Base Case - 2050



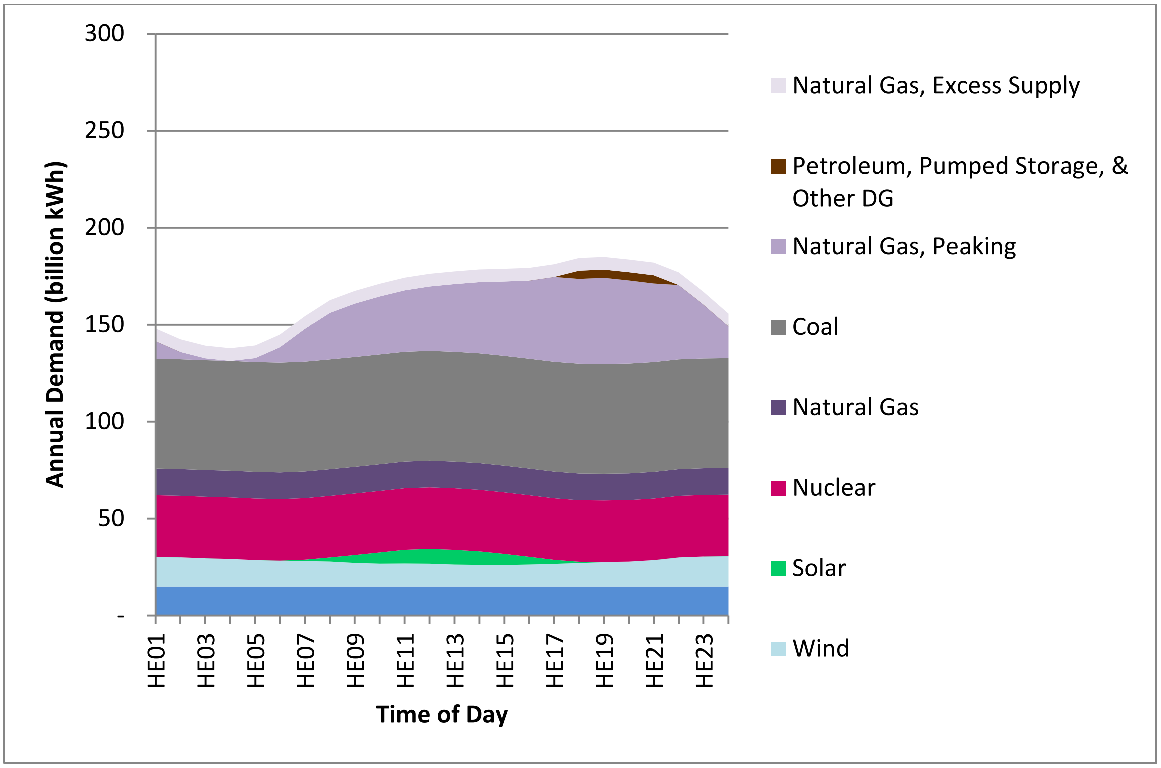
The Base Case 2050 shows the most dramatic impact of both renewables and natural gas conversion to base load. The renewables shape pairs very well with the initial ramp up of demand in the morning to afternoon, minimizing peaking technologies in the first half of the day. As the load stays high as the sun goes down, peaking technologies are then utilized but in a much shorter timeframe than in previous decades. This supply shift creates significant emissions reductions.

Renewables now account for 29% of the supply and, including nuclear, 41% of all power has zero emissions. This decline in emissions free power is found by the retirement of nuclear facilities outpacing renewable growth.

The average CO2e emissions are 330 g/kWh. The top power producing resource is now base load natural gas instead of coal.

3.3 TOU Case

Figure 7 TOU Case – 2020
Assumes 1% BEV saturation with morning charging only.

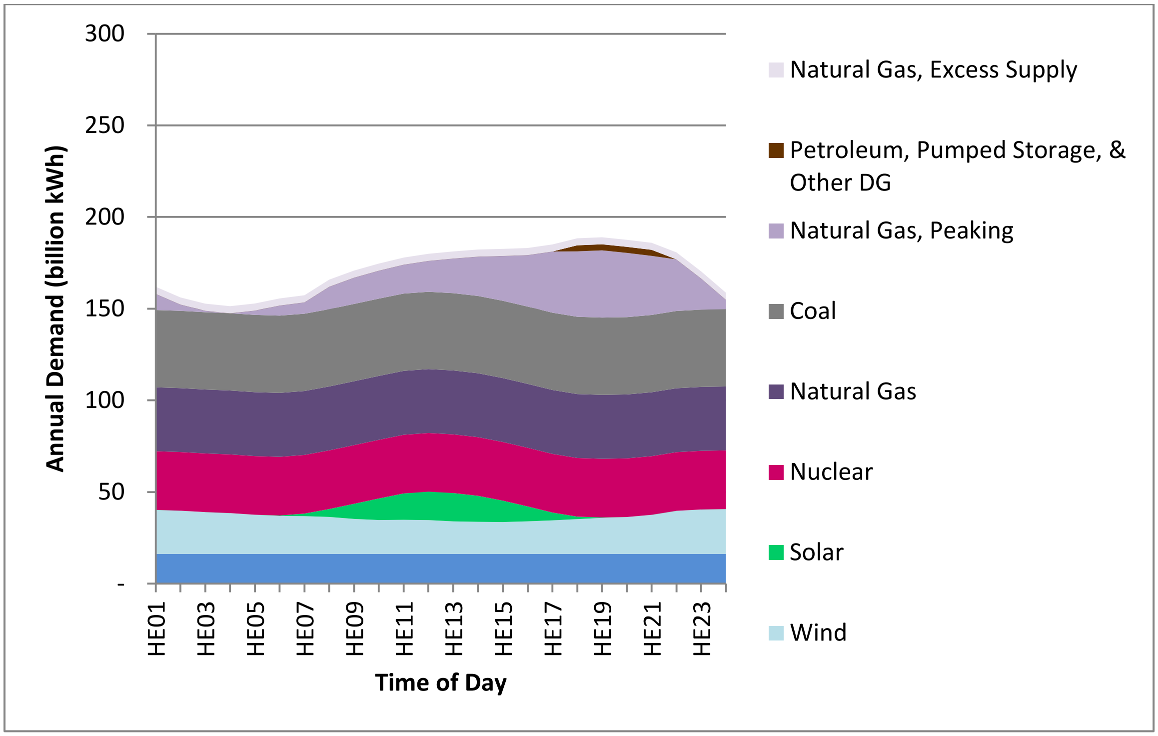


The TOU 2020 case considers 1% of all light vehicles converting to BEV utilizing Level 1 Charging. The vehicles are charged in the morning hours only. This results in a flatter demand curve, allowing for a slight increase in base load natural gas generation of roughly 10% (295 billion kWh to 329 billion kWh).

The average CO2e emissions are 418 g/kWh. This is a 0.25% reduction in grid emissions compared to Base Case 2020.

The top power producing resource is coal.

Figure 8 TOU Case – 2030
Assumes 9% BEV saturation with morning charging only.

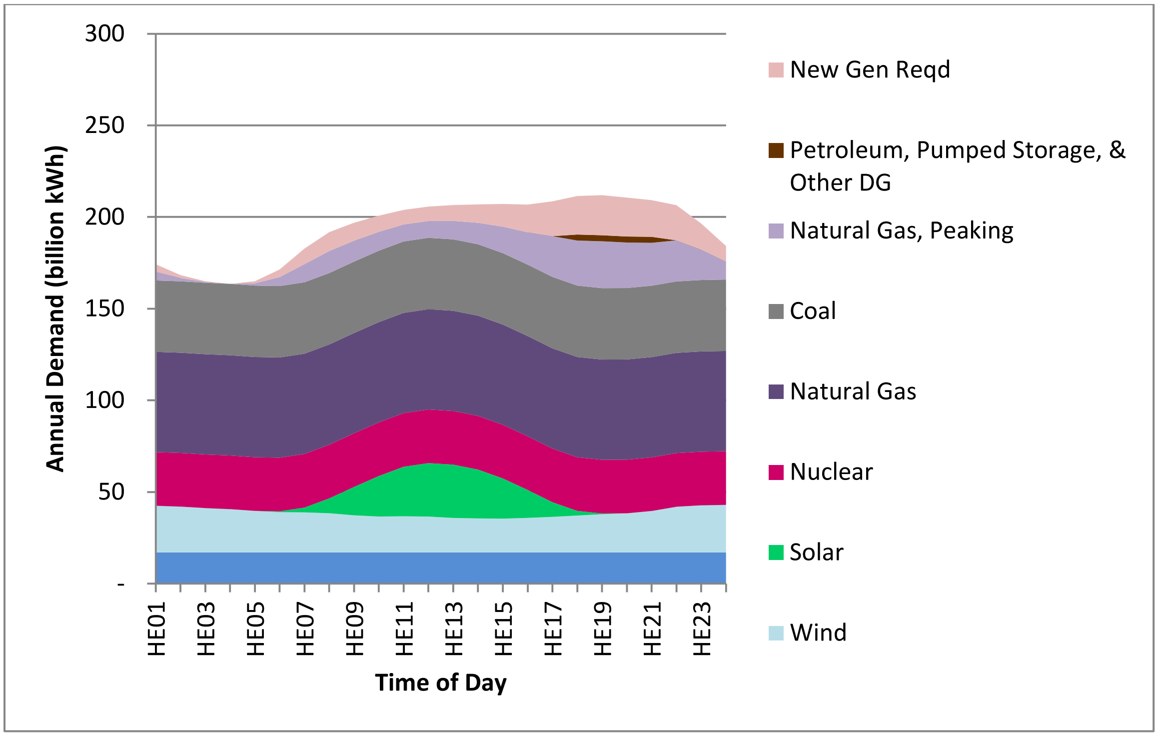


The TOU Case 2030 shows an expansion of BEVs to 9% of the light vehicle market utilizing Level 1 Charging. These vehicles are all charge at the same times in the morning hours, resulting in a flatter demand curve. This flat demand curve allows for 304 billion kWh of natural gas generation to shift to base load, an increase of 57% in base load natural gas generation compared to Base Case 2030.

The average CO2e emissions are 346.73 g/kWh. This is a 2.17% reduction in grid emissions compared to Base Case 2030.

The top power producing resource is coal.

Figure 9 TOU Case – 2050
Assumes 52% BEV saturation with continuous charging inverse of normal demand.



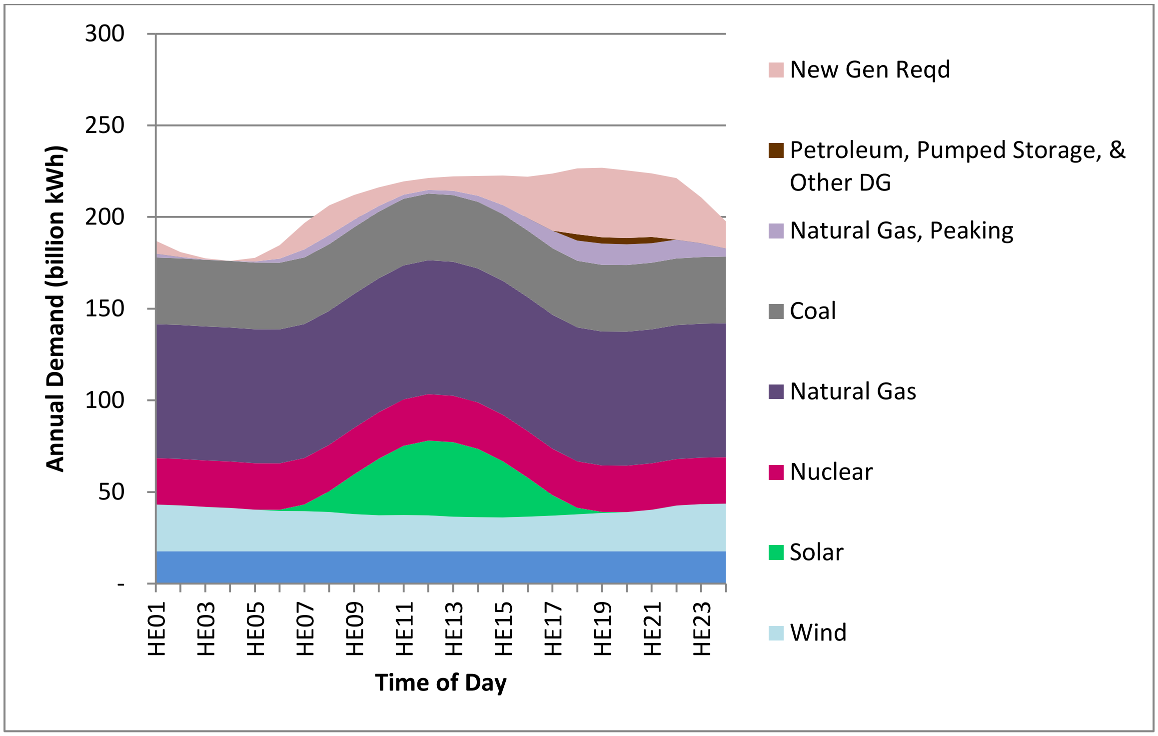
The TOU Case 2040 sees further impacts of both a flatter demand curve and renewable expansion. Additionally, with a significant demand increase from BEVs, new generation is required to be installed. This new generation is to include all technologies and is considered to have the average composition of the dispatch model in that given year.

The BEV demand shape is forecasted differently in this model to consider a more continuous charging structure, as the market penetration at this level would assume a significant BEV infrastructure buildout.

In this case, natural gas base load now accounts for 81% of natural gas generation and 28% of all power supplied to the grid, becoming the top generation resource.

The average CO2e emissions are 333 g/kWh. This is a 2.23% reduction in grid emissions compared to Base Case 2040.

Figure 10 TOU Case – 2050
Assumes 69% BEV saturation with continuous charging inverse of demand.



The TOU Case 2050 shows further impacts on the demand curve and renewable expansion. The solar mid-day peak closely tracks the new demand curve, minimizing peak technologies.

As in TOU Case 2040, the BEV demand shape considers a continuous charging scenario.

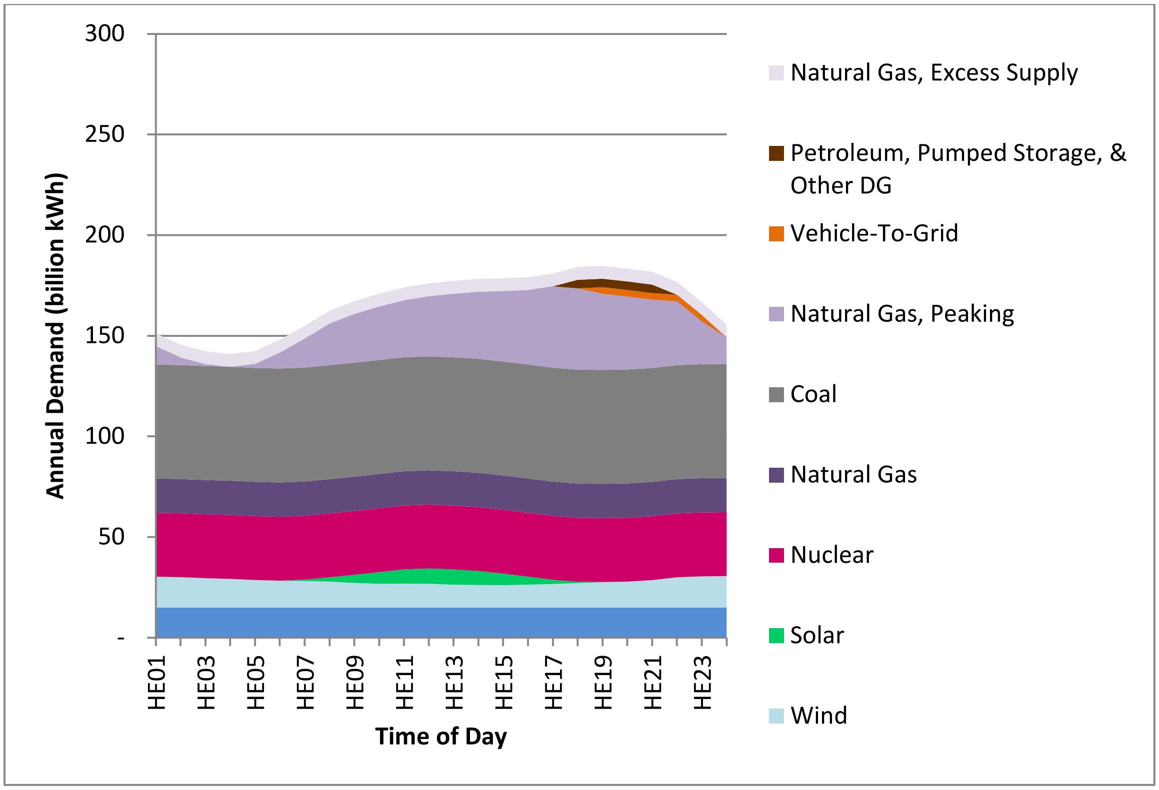
In this case, natural gas base load now accounts for 94% of natural gas generation and 34% of all power supplied to the grid, remaining the top generation resource. This amount is double that of coal, which is a distant second at 17% of power sold.

The average CO2e emissions are 318 g/kWh. This is a 3.45% reduction in grid emissions compared to Base Case 2050.

3.4 V2G Case

Figure 11 V2G Case – 2020

Assumes 1% BEV saturation, 50% as TOU only and 50% as V2G. Both TOU and V2G assume morning charging and the V2G provides evening dispatch.

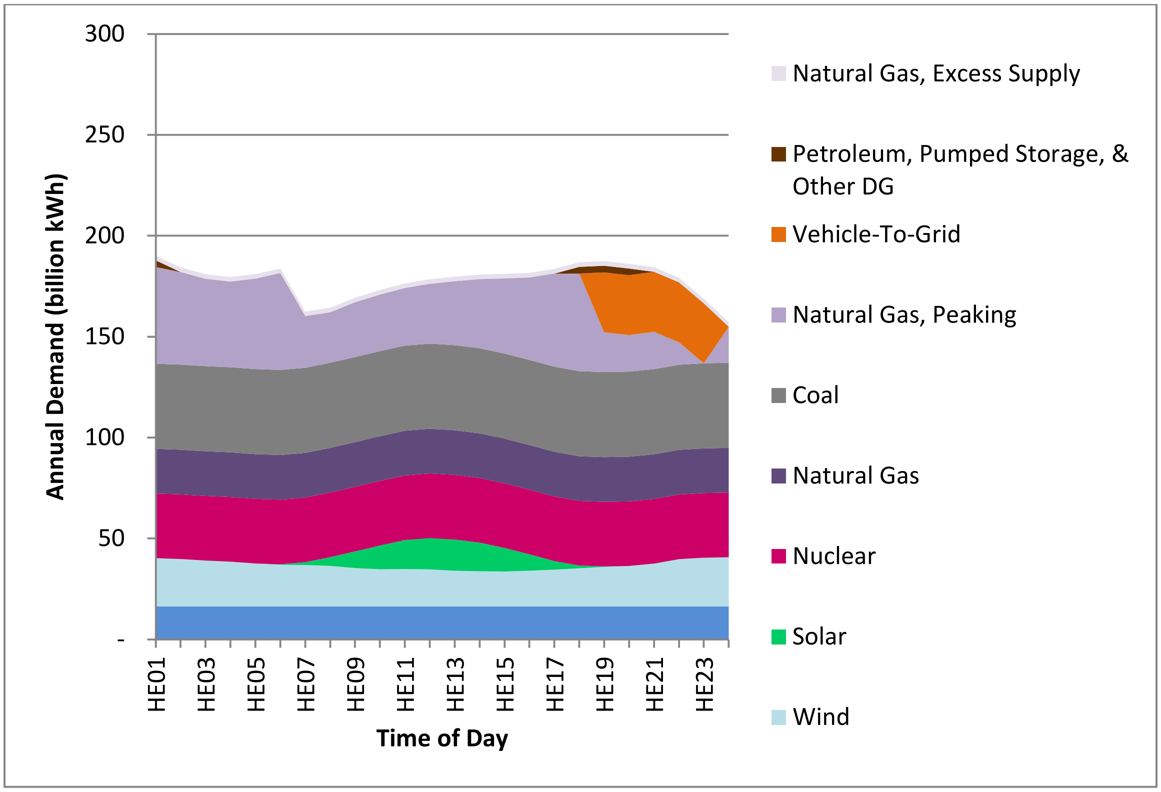


The V2G 2020 Case includes a 1% expansion of BEVs, half of which are Level 1 charging identical to the TOU scenario. The second half are Level 2 charging that export power in the evening, shown in the chart as Vehicle-To-Grid. It's important to note that Vehicle-To-Grid technology in this case does not create power, but shifts power use/supply in time. Since all vehicles, both TOU and V2G, drive the same distance, they both use the same amount of energy on a net basis.

In this case, due to introduction of V2G, natural gas generation increases further from the TOU Case and the Base Case, increases of 24% and 39% respectively. This change along with a reduction of peaking use in the evening creates an emissions profile of 414 g/kWh, a reduction of 1.37% per kWh compared to Base Case 2020.

The top power producing resource is coal. V2G accounts for 0.43% of all power sold.

Figure 12 V2G Case – 2030
Assumes 9% BEV saturation, 50% as TOU only and 50% as V2G. Both TOU and V2G assume morning charging and the V2G provides evening dispatch.

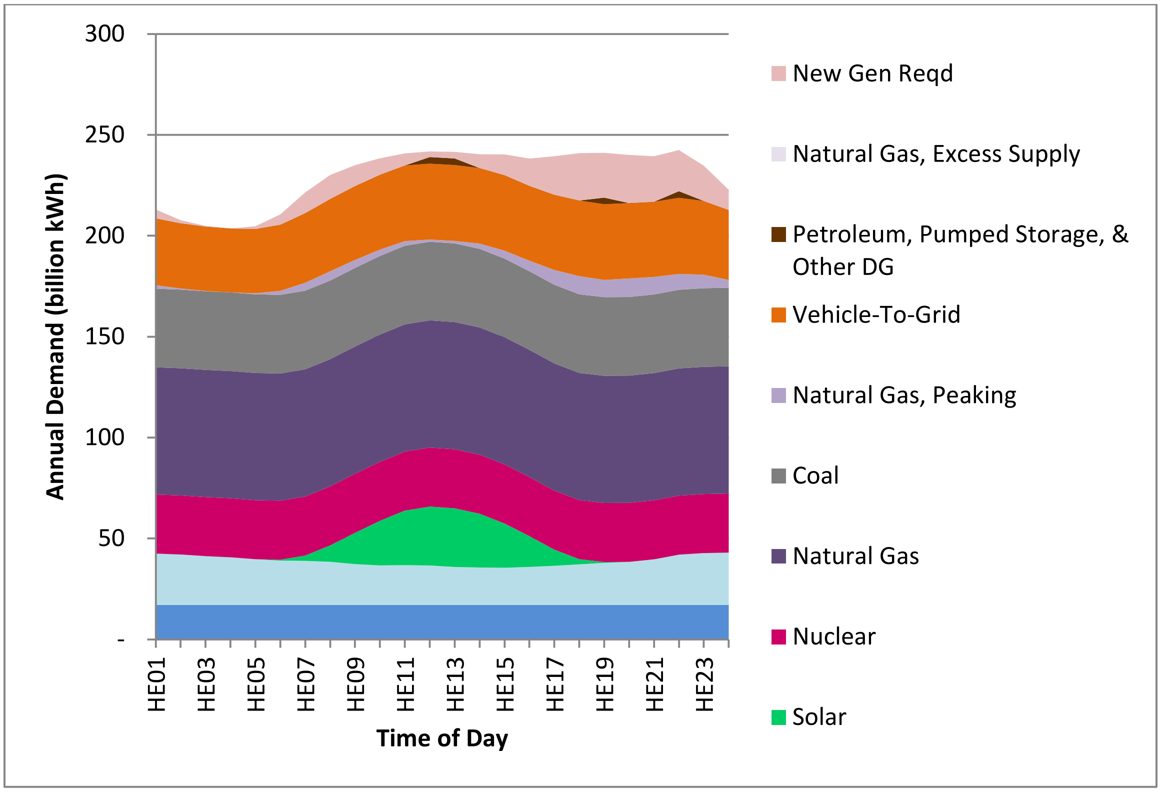


The V2G 2030 Case shows a further expansion of V2G. However, due to the demand and supply timing considered in this case, grid efficiency declines. The volatility of natural gas peaking supply paired with a second peak in the morning for BEV charging compound to reduce the benefit of BEVs overall.

As a comparison, there is more natural gas base load in the Base 2030 Case than in the V2G 2030 Case. These inefficiencies result in only a slight improvement to grid emissions, a 2.07% reduction to 347.06 g/kWh. This g/kWh emissions value is higher than the TOU 2030 Case, indicating that if charging and exporting are contained in the morning and evening only, the grid is less efficient by allowing V2G technologies.

The top power producing resource is coal. V2G accounts for 3.51% of all power sold.

Figure 13 V2G Case – 2040
Assumes 52% BEV saturation, 50% as TOU only and 50% as V2G. Both TOU and V2G assume continuous charging inverse of standard demand. V2G provides continuous dispatch paired with the aggregate demand curve.

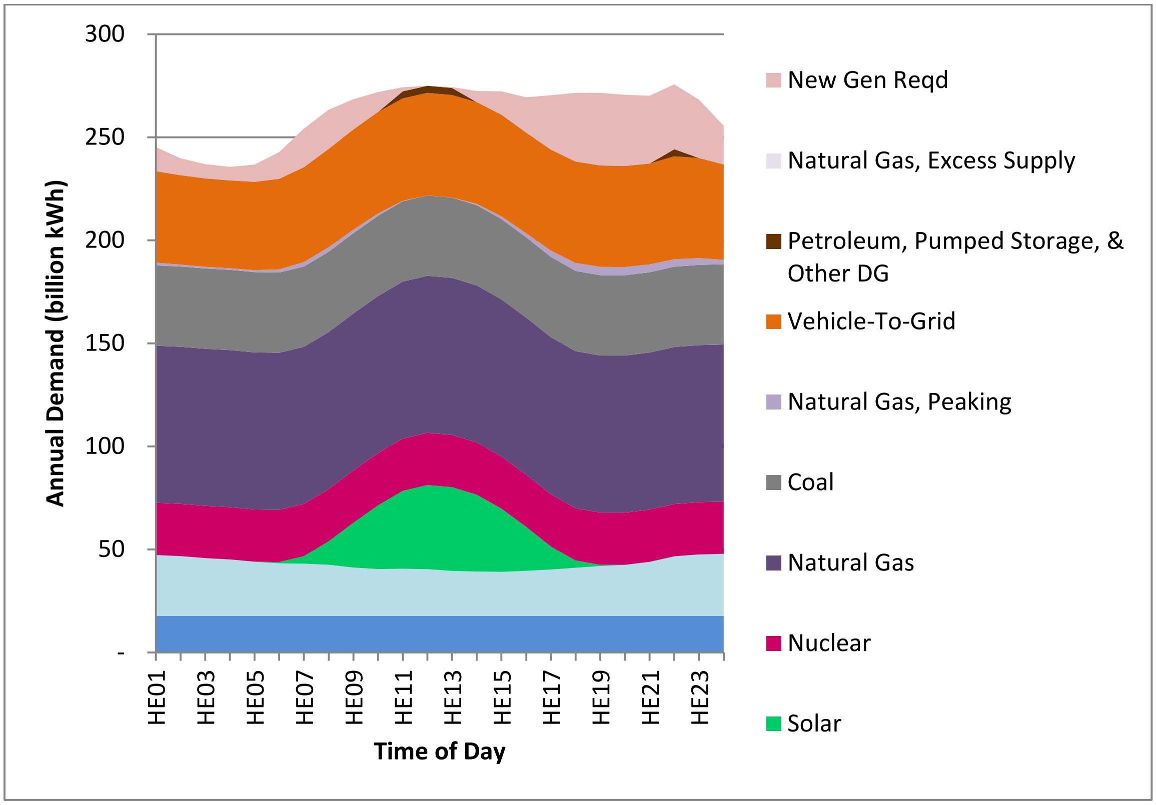


To alleviate the issues caused by strict charging and exporting rules in the V2G 2030 case, the 2040 model assumes a continuous charging and exporting model, as outlined in *Appendix A – Assumptions*. The new load curve creates a new mid-day peak. It is important to note that some vehicles will be charging while others export. V2G now accounts for roughly one quarter of all like vehicles on the road, resulting in a significant level of BEV dispatched power.

By assuming a more fluid charge/export rule, the load curve is much flatter. In addition, to me the increased demand, new generation is required. As a result of all these changes, natural gas increases by 97% compared to Base 2040 Case and 15% compared to TOU 2040 Case.

The top power producing resource is base load natural gas. V2G accounts for 15.55% of all power sold.

Figure 14 V2G Case – 2050
Assumes 69% BEV saturation, 50% as TOU only and 50% as V2G. Both TOU and V2G assume continuous charging inverse of standard demand. V2G provides continuous dispatch paired with the aggregate demand curve.



With a BEVs constituting a large majority of light vehicles on the road, half of which being capable of exporting power, V2G has effectively shifted the dispatch model. An expanded mid-day peak remains, as first appeared in the V2G 2040 Case. Base load natural gas shows further expansion, an increase of 62% compared to Base 2050 Case and 4% compared to TOU 2040 Case.

As in previous cases, new generation is acquired and all associated assumptions are outlined.

The top power producing resource is base load natural gas. V2G accounts for 18.28% of all power sold, behind only base load natural gas and surpassing coal for the first time.

3.5 Generation Resource Summary

The following tables summarize the total generation in billion kWh from a given source and the percentage of that years generation that resource provides.

Table 2 Forecasted Generation Summary

	Total Generation				*Percentage of Total*			
Base Case	***2020***	***2030***	***2040***	***2050***	***2020***	***2030***	***2040***	***2050***
Coal	1,358.58	1,011.89	934.79	872.50	34.08%	24.49%	21.25%	18.60%
Nuclear	761.76	768.02	701.81	608.15	19.11%	18.59%	15.95%	12.97%
Natural Gas - Base Load	295.80	532.25	843.09	1,130.31	7.42%	12.88%	19.16%	24.10%
Natural Gas - Peaking	660.50	649.99	604.54	582.08	16.57%	15.73%	13.74%	12.41%
Natural Gas - Excess Supply	164.85	164.63	163.87	161.98	4.14%	3.98%	3.72%	3.45%
Solar	54.50	111.14	208.87	292.02	1.37%	2.69%	4.75%	6.23%
Wind	314.15	490.22	520.58	604.64	7.88%	11.86%	11.83%	12.89%
Other Renewables	359.42	390.54	409.31	425.12	9.02%	9.45%	9.30%	9.06%
Petroleum, Pumped Storage & DG	16.91	13.19	13.13	13.77	0.42%	0.32%	0.30%	0.29%
New Generation Required	-	-	-	-	0.00%	0.00%	0.00%	0.00%
Vehicle-to-Grid	-	-	-	-	0.00%	0.00%	0.00%	0.00%
Total	3,986.46	4,131.87	4,399.99	4,690.57	100.00%	100.00%	100.00%	100.00%

	Total Generation				*Percentage of Total*			
TOU Case	***2020***	***2030***	***2040***	***2050***	***2020***	***2030***	***2040***	***2050***
Coal	1,358.58	1,011.89	934.79	872.50	34.08%	24.49%	20.08%	17.16%
Nuclear	761.76	768.02	701.81	608.15	19.11%	18.59%	15.07%	11.96%
Natural Gas - Base Load	329.62	836.62	1,312.75	1,753.52	8.27%	20.25%	28.20%	34.48%
Natural Gas - Peaking	634.74	418.21	298.75	120.86	15.92%	10.12%	6.42%	2.38%
Natural Gas - Excess Supply	156.78	92.05	-	-	3.93%	2.23%	0.00%	0.00%
Solar	54.50	111.14	208.87	292.02	1.37%	2.69%	4.49%	5.74%
Wind	314.15	490.22	520.58	604.64	7.88%	11.86%	11.18%	11.89%
Other Renewables	359.42	390.54	409.31	425.12	9.02%	9.45%	8.79%	8.36%
Petroleum, Pumped Storage & DG	16.91	13.19	13.13	13.77	0.42%	0.32%	0.28%	0.27%
New Generation Required	-	-	255.50	394.50	0.00%	0.00%	5.49%	7.76%
Vehicle-to-Grid	-	-	-	-	0.00%	0.00%	0.00%	0.00%
Total	3,986.46	4,131.87	4,655.50	5,085.07	100.00%	100.00%	100.00%	100.00%

V2G Case	*Total Generation* 2020	2030	2040	2050	*Percentage of Total* 2020	2030	2040	2050
Coal	1,358.58	1,011.89	934.79	872.50	33.94%	23.64%	16.96%	14.02%
Nuclear	761.76	768.02	701.81	608.15	19.03%	17.94%	12.73%	9.77%
Natural Gas - Base Load	408.77	531.78	1,513.15	1,828.73	10.21%	12.42%	27.45%	29.39%
Natural Gas - Peaking	559.62	759.35	98.35	45.65	13.98%	17.74%	1.78%	0.73%
Natural Gas - Excess Supply	152.75	55.75	-	-	3.82%	1.30%	0.00%	0.00%
Solar	54.50	111.14	208.87	292.02	1.36%	2.60%	3.79%	4.69%
Wind	314.15	490.22	520.58	604.64	7.85%	11.45%	9.44%	9.72%
Other Renewables	359.42	390.54	409.31	425.12	8.98%	9.12%	7.42%	6.83%
Petroleum, Pumped Storage & DG	16.91	13.19	13.13	13.77	0.42%	0.31%	0.24%	0.22%
New Generation Required	-	-	255.50	394.50	0.00%	0.00%	4.63%	6.34%
Vehicle-to-Grid	16.49	148.41	857.46	1,137.78	0.41%	3.47%	15.55%	18.28%
Total	4,002.95	4,280.28	5,512.96	6,222.86	100.00%	100.00%	100.00%	100.00%

3.6 Emissions Results

There were multiple data points sought in the results. First, the emission efficiency of the grid improves in the TOU scenario and further still in the V2G scenario as seen in the table below.

Table 3 Electric Grid Emissions Summary

Summary - g CO2e/kWh	2020	2030	2040	2050
Base Case	419.30	354.40	340.44	329.77
TOU Case	418.26	346.73	332.86	318.39
V2G Case	413.90	340.01	272.75	254.16
Summary - Total Grid Emissions	**2020**	**2030**	**2040**	**2050**
Base Case	1,602	1,406	1,442	1,493
TOU Case	1,602	1,401	1,637	1,748
V2G Case	1,592	1,426	1,575	1,684

This table demonstrates that overall grid emissions efficiency improves in the TOU Scenario from 0.24% in 2020 to 3.45% in 2050 just by the expansion of BEV and considering time of use. V2G provides grid emissions efficiency improvements from 1.2% in 2020 to 22.93% in 2050.

The vehicles individually also achieve better emissions performance when considering the ultimate fuel source. The assumption that BEVs in general have lower net emissions than a standard gasoline fueled vehicle was clearly anticipated. The "Base BEV" test assumes the annual emissions per kWh of the grid and assigns that value to every kWh consumed by a BEV. The model tested how this can be improved by assuming time of use and vehicle to grid. Those results are in the table below. The V2G Scenario considers both the emissions of the electricity consumed and the emissions of the electricity replaced.

Table 4 Vehicle Emissions Summary

	Per Vehicle Emissions, CO2 metric tons						
	No BEV	***Base BEV***	***TOU***	***V2G***	***Base Savings***	***TOU Savings***	***V2G Savings***
2020	2.40	1.24	1.17	0.93	48.48%	51.13%	61.41%
2030	1.93	1.04	0.98	2.22	45.81%	49.12%	-15.05%
2040	1.77	1.00	0.98	0.81	43.22%	44.66%	54.33%
2050	1.63	0.97	0.94	0.76	40.41%	42.45%	53.50%

The results show that time of use considerations can reduce net emissions from a BEV compared to the Base BEV. Additionally, V2G creates more emissions savings than both the TOU and Base BEV scenarios in the 2040 and 2050 cases.

Further outlined in the *Section* 5 - Discussion section, the per vehicle emissions in the 2030 V2G case underperform due to inefficiencies caused by rapid ramping up and down of BEV exported power and the creation of a second, morning peak.

More importantly, when combining both the total emissions of the overall electric system as well as the total emissions from the entire vehicle fleet considered, emissions are also reduced in both the TOU and V2G cases compared to the base case, as seen in the table below.

Table 5 Total Emissions Summary

Total System Emissions, million metric tons of CO2e					
	Base Case	***TOU***	***V2G***	***TOU, %***	***V2G, %***
2020	2,259	2,252	2,242	0.32%	0.74%
2030	1,974	1,922	1,987	2.67%	-0.64%
2040	2,003	1,946	1,884	2.85%	5.94%
2050	2,051	1,998	1,935	2.59%	5.70%

Section 4 - Discussion

The V2G Scenario provides substantial improvements by flattening the demand and shifting power from peak times to off-peak times. The V2G results in notable emissions savings when considering the overall load increases by 22.38% in 2050 but the total emissions from the grid only increases by 12.79% at that time. The grid emissions efficiency is realized by a conversion of peaking, single cycle natural gas turbine power facilities to a more efficient combined cycle, base load technology. As the load increases and flattens out, inefficient peaking technologies are no longer needed. In addition, these peaking technologies are replaced by battery storage that loads up during off peak hours, further improving efficiencies. The change from peaking to base load natural gas power supply can be seen in *Table 7 Base Load NG Supply* and *Table 8 Peaking Natural Gas Supply* located in *Appendix B – Additional* Tables.

One outlier is the 2030 V2G Scenario. This scenario does not consider high enough BEV saturation to calculate demand/discharge on a continuous basis as the 2040 and 2050 models anticipate. Since BEVs in this scenario have grown significantly and are all on a similar schedule of charging and exporting power to the grid, the resulting dispatch curve is very similar in effective impact as the CAISO "duck curve" created by excess solar capacity. This similarity is on implications to dispatch, not in shape itself.

The CAISO “duck curve’ is now a well-known phenomenon in the electric industry. The curve is caused by large amounts of solar deployed throughout the system. As the sun goes down, all of solar power begins to power down, requiring large amounts of natural gas peaking capacity to come online quickly. A similar impact is felt in the 2030 V2G Scenario as a large amount of BEV exporters are online and then rapidly offline. In addition, the system experience effectively two peak periods, one in the morning during charging and one in the evening.

Due to specifically timed heavy ramping up and down of an export technology, in this case batteries, it requires a counteracting ramp down or up of inefficient generation technologies. These volatile shifts create emissions inefficiencies as many fast response technologies utilize fossil fuels.

Overall, the results clearly show the consideration of time of use and V2G can further enhance the emissions savings of an electric vehicle on its own. In addition, the results show that the impact of BEV expansion on the dispatch model create further efficiencies in emissions that create even greater emissions savings compared to the status quo.

Appendix A – Assumptions

A.1 Electric Vehicle Type Considered

The criterion to consider for V2G is the ability to plug into the grid. Standard hybrid vehicles do not currently have plug in capability; one types of electric vehicle is the primary focus of this research, battery electric vehicles or BEVs.

BEVs run solely on electric charge with no conventional fuel back up. As a result of the design concept, BEVs require a larger battery capacity and are capable of driving much further distances powered purely on electricity. For this study, the 2017 Chevrolet Bolt EV is utilized as the standard BEV. This vehicle has a range of 238 miles fully charged and a battery capacity of 60 kWh (Bolt EV).

A.2 Vehicle Charging Technology Considered

There are multiple technologies and options to charge electric vehicles. For standard operation, there is Level 1 and Level 2 charging utilizing readily available alternating current (AC) power outlets. Level 1 charging is plugging an electric vehicle into a standard 120 V outlet. Due to the low voltage, this charges the battery at 1300 watts (EV Home Charging Station FAQs) resulting in roughly 4 miles per hour of charge (Saxton, 2011). Therefore, to fully charge the BEV to 60 kWh from empty, it would take approximately 46.2 hours. This option requires little to no investment from the homeowner, as it is very likely a 120 V outlet is readily available for car charging in their garage or outside their home.

Level 2 Charging requires a small investment from a homeowner while improving charge times. The range of investments to upgrade to Level 2 Charging at home is between $950-$2500 depending on location, equipment selected, and labor (EV Home Charging Station FAQs). The upgrade creates a 240V outlet to plug in the vehicle, which can charge a car at 6600 watts resulting in roughly 25 miles per hour of charge (Charging is No Big Deal). Not all vehicle batteries are designed with the capability to accept all 6600 watts and can limit the amount of power received (EV Home Charging Station FAQs). To fully charge our standard BEV from empty, it would take 9.1 hours.

DC Fast Charging is the most likely option for charging any compatible EV in a gas station like scenario. The most recognizable version of this technology is the Tesla Supercharger. DC Fast charging can charge a vehicle with 60-100 miles of range in 20 minutes or less (Charging on the Road). In regards to total charge time, this is a significant departure from the Level 1 and Level 2 charging options which utilize standard AC power. Due to the capital requirements and potential strain wide deployment of DC Fast Charging can cause on the electric infrastructure itself (Saxton, 2011), this study does not consider or include DC Fast Charging. By its design, DC Fast Charging is for convenience and therefore, load shifting to off-peak hours is not the intention of the technology.

There are other charging options either available or currently deployed (i.e. AC Fast Charging), but the three technologies listed above are the most prominent and readily available currently.

A.3 Charging and Driving Assumptions

To account for these options, certain driving and charging behaviors were assumed. The average commute is assumed to be 32 miles round trip (Dunckley, 2016); therefore the model estimates 16 miles in the morning and 16 miles in the evening. This commute is assumed to occur between 8:00AM-9:00AM into the office and 5:00PM-6:00PM returning home. The vehicle is assumed to be plugged in at all hours the car is parked at home and no charging is done at the office.

For the TOU case in years 2020 and 2030, the vehicle is assumed to be on a charging timer allowing charging after midnight only. This results in the vehicle fully charging from between

12:00AM-7:00AM. For years 2040 and 2050, BEV proliferation has grown to such proportions that modeling the demand in a similar fashion creates night time super peaks. As a result, the assumption for demand is much more fluid and is shaped as the inverse shape of the normal days demand.

Utilizing PJM data, over the past 5 years the average 5 peak hours in a day are between hours 17 and 21, which is 5:00PM-10:00PM. As mentioned before, the 5:00PM hours is already slotted for commuting home, so therefore the vehicles in this model could supply power to the grid upon getting home from 6:00PM and 11:00PM. The 10:00PM-11:00PM hour is the 10th highest demand hour in an average day, but the highest remaining demand hour available for any vehicle to supply power.

In this model, the TOU vehicles will charge utilizing a 120V, Level 1 charging station. The V2G vehicles will utilize a 240V, Level 2 charging station.

The BEV therefore, once fully charged by 8:00AM, utilizes roughly 8.06 kWh to commute to and from work. The BEV would then have approximately 49.44 kWh available for grid export upon return home during peak hours assuming it left fully charged. Export is limited to 6.6 kW capacity and we do not intend to draw the battery below the 25% to allow for emergency use and to mitigate any potential charging error risk. The V2G vehicle will then charge between hours 12:00AM thru 7:00AM, and then export power from 6:00PM thru 11:00PM.

A.4 Forecasted Demand

To create a daily shape to electricity demand, five years of PJM demand data was accumulated on a 24 hour schedule. The average of this 24 hour schedule over the five years was utilized to create a daily usage distribution, a percentage of the total daily kWh used in that hour. The AEO also has a total demand forecast out to 2050. Using the create usage distribution, a 24 hour schedule of demand was extrapolated out to 2050. This demand curve drives the dispatch curve outlined in the following "Forecasted Generation" section.

A.5 Forecasted Generation

To determine emissions for the grid itself to understand the emissions per kWh utilized by the electric vehicles, a dispatch curve must be created to understand time of use and supply from the BEV itself. The 2017 EIA Annual Energy Outlook ("AEO") forecasts projects electricity generation by source out to 2050. With this information, the following assumptions in the dispatch curve were made:

- All Renewables are assigned first priority. Renewables are designated as "Wind", "Solar" and "Other Renewables" in this model.
- Nuclear and Coal, due to their inability to efficiently ramp up and down, receive second and third priority respectively.
- "Base-Load Natural Gas" receives fourth priority in dispatch and "Peaking Natural Gas" receives the fifth dispatch priority. "Base-Load Natural Gas" is assumed to be combined cycle but is modeled to only supply enough to meet the minimum daily load.
- "Petroleum, Pumped Storage, and Other DG" is designed as quickly dispatched technologies that create power during the four peak hours in a day.

Coal, Nuclear, Base-Load Natural Gas and Other Renewables all assume a flat dispatch model. Peaking Natural Gas is shaped to meet remaining demand. Wind is modeled on wind generation data from ERCOT. Solar is shaped based on data generated from NREL's PVWatts calculator.

A.6 BEV Demand

As the daily BEV usage depending on a vehicle as a TOU vehicle or a V2G vehicle, the demand curves differ. This demand curve and overall impact on the aggregate demand curve greatly depends on the population of BEVs in use. To estimate this, a historic count of standard, light vehicles was employed to develop a “historic growth” factor to be applied to future years from 2015 through 2050. By assuming the average growth rate of the previous ten years (2005-2015) (Number of vehicles registered in the United States from 1990 to 2015 (in 1,000s)), the total car stock rises approximately 0.75% annually.

To estimate the total BEV stock, a study of Grantham Institute estimate future BEV saturation as a percentage of total cars driven globally. This percentage was then applied to the forecast total car population to result in the BEV count listed in

Table 9 Electric Vehicle Count - On the Road located in *Appendix B – Additional* Tables.

A.7 CAFÉ Standards

The emissions comparison for gasoline to electric relies on CAFÉ standards assumptions going out to 2050. CAFÉ standards only currently exist going out to 2025 and the EIA AEO projections are conservatively flat past 2025. Therefore, multiple assumptions were made past that time frame. The following CAFÉ Standards were assumed for equivalent vehicles:

- 2020 - 44.2 mpg (existing rule)
- 2030 - 55.0 mpg
- 2040 – 60.0 mpg
- 2050 – 65.0 mpg

It is important to note that higher CAFÉ standards would allow for fewer saving from BEV options, as the gasoline option would burn less fuel for an equal amount of distance driven.

A.8 Fossil Fuel Emissions

All emitting technologies were assigned a CO2e emissions estimate in grams per kWh generated. Those estimates were as follows:

- Coal 816 g/kWh

- Combined Cycle Natural Gas 403 g/kWh
- Simple Cycle Natural Gas 552 g/kWh
- Petroleum 733 g/kWh

Coal, Combined Cycle Natural Gas and Simple Cycle Natural Gas assumptions were sourced from Scientific American (Wogan, 2013). Petroleum emissions assumption was sourced from a World Nuclear Association Report (World Nuclear Association).

In both the TOU and V2G Scenario, additional generation is required to meet the increased demand of power BEVs. The emissions assumptions are that of the average system in the given scenario. As an example, if a given scenario has emissions per kWh of 400, any new generation required in that hour will be assigned a 400 C02e/kWh value so as not to move the average. Therefore, the new generation to fill the requirement is expected to represent the composition of the generation supply itself at that given time, scenario and hour of dispatch.

In addition, the combustion of gasoline was assigned an emissions value per gallon. This value is 20 lbs. of CO2e per gallon burned.

Appendix B – Additional Tables

Table 6. PJM Load Distribution

PJM Load Distribution							
HE01	***HE02***	***HE03***	***HE04***	***HE05***	***HE06***	***HE07***	***HE08***
3.67%	3.52%	3.43%	3.40%	3.44%	3.59%	3.87%	4.08%
HE09	***HE10***	***HE11***	***HE12***	***HE13***	***HE14***	***HE15***	***HE16***
4.21%	4.30%	4.39%	4.44%	4.47%	4.50%	4.51%	4.52%
HE17	***HE18***	***HE19***	***HE20***	***HE21***	***HE22***	***HE23***	***HE24***
4.57%	4.65%	4.67%	4.63%	4.59%	4.46%	4.20%	3.90%

Table 7. 2020 Base Case Dispatch Model

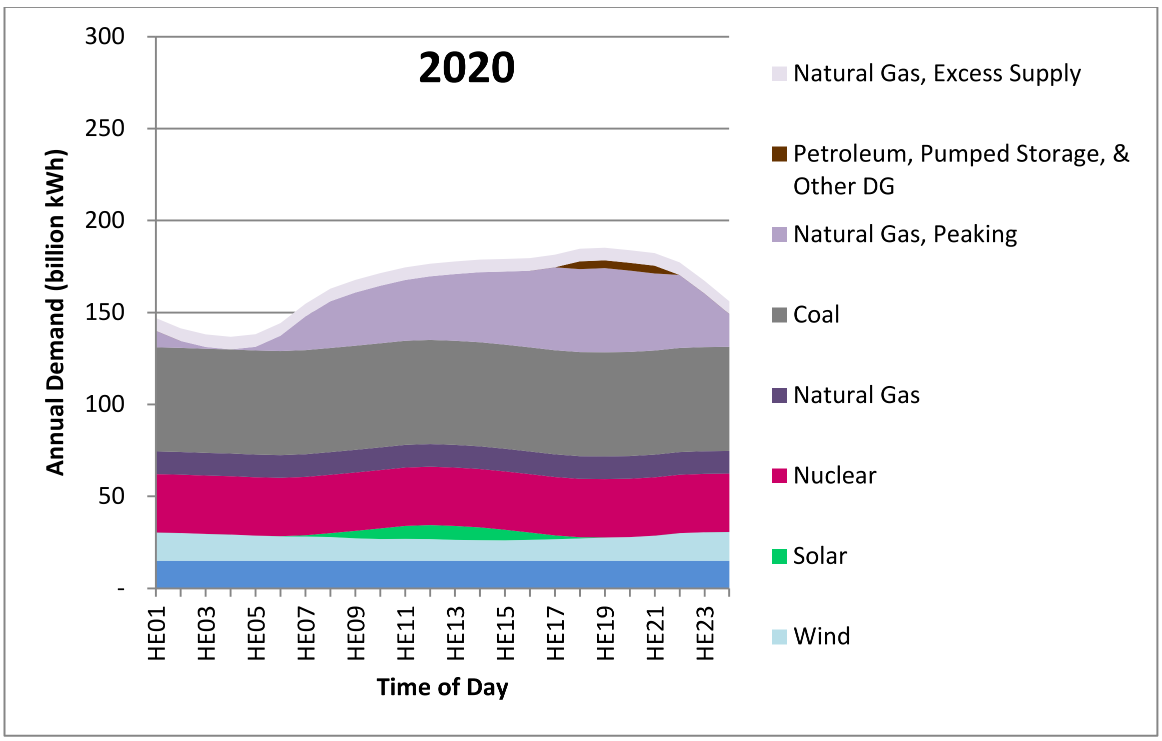


Table 8 Base Load NG Supply

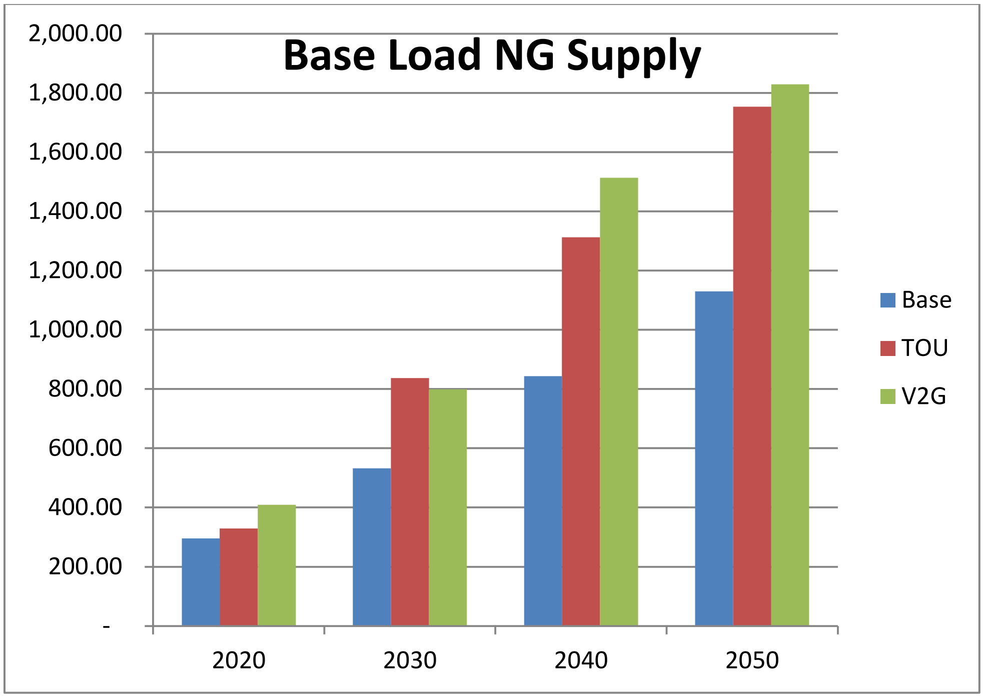


Table 9 Peaking Natural Gas Supply

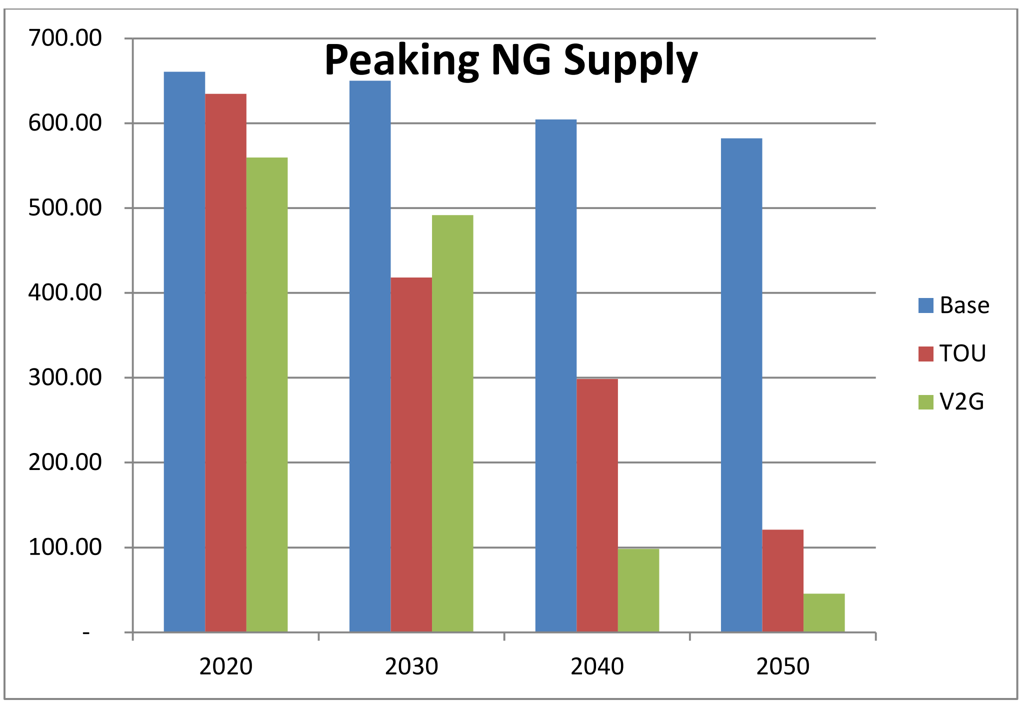
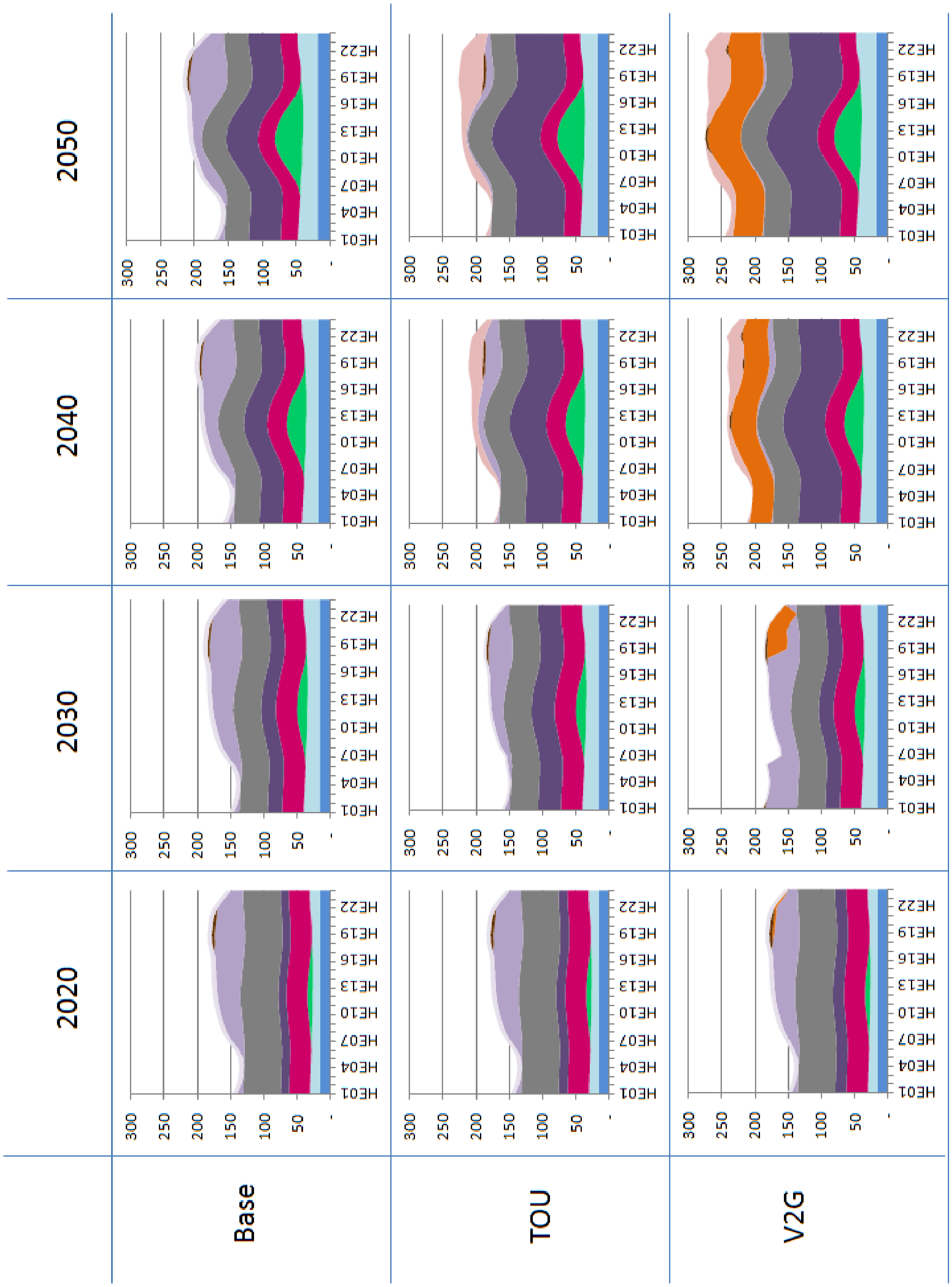


Table 10 Electric Vehicle Count - On the Road

Year	*% of Total*	*BEV Count*
2020	1.00%	2,736,130
2030	9.00%	24,625,173
2040	52.00%	142,278,779
2050	69.00%	188,792,995

Appendix C - Model Chart Summary



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Curriculum Vitae

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Summary

I am an Energy Finance and Business Development Professional with over 8 years of experience developing over $1 billion in distributed energy projects including solar and CHP. My goal is to find a role that leverages my analytical and forecasting skills in a business development and strategy function.

Experience

Touchstone Energy Cooperatives ***(2016-Current)***

Director, Business Development *Dec 2016 – Current*

- Initiated first business development oriented newsletter
- Created and hosted webinar content with a focus on policy, technology and market trends
- Worked with national energy managers to better manage the cooperative business model
- Crafted and started new key account training offerings to members

South Jersey Industries (SJI) ***(2009-2016)***

General Manager, Corporate Development (SJI) *Apr 2016 – Dec 2016*

- Manage M&A and divestiture processes, including origination, structuring, and execution
- Responsible for market research, valuation and executive reporting
- Manage preferred supply commodity business with $2M in annual margin

Manager, Business Development & Expansion (SJES) *Nov 2013 – Apr 2016*

- Closed $7.5MM in margin through unique financial arrangements
- Commenced first company social media marketing and SEO campaigns
- Closed over 85 MW and $250MM in capital expenditures of renewable energy projects
- Participated in local and regional organizations to promote brand in multiple chair roles

Manager, Project Development (Marina Energy) *Jun 2011 – Nov 2013*

- Closed over 90 MW and $400MM in capital expenditure of photovoltaic projects
- Developed, pro formed and financed $55M acquisition of New England based steam loop
- Managed construction of $180MM central utility and CHP plant serving a gaming facility

Jr. Manager, Project Development (Marina Energy) *Jun 2009 – Jun 2011*

- Modeled and closed over 10MW of photovoltaic solar projects worth over $70MM
- Evaluated operating efficiencies of multiple facilities throughout energy portfolio
- Developed working screening models for CHP, LFGE, and PV opportunities

Education

M.S. Energy Policy & Climate *2015 – 2017*
Johns Hopkins University
Focus on Renewable Energy Policy

Master of Business Administration *2012 - 2014*
Villanova University
Concentrations in Finance & Strategic Management

B.S. Energy Business and Finance *2005 - 2009*
Pennsylvania State University
Minors in Economics and Italian Language

Certifications & Awards

- Certified Energy Manager (CEM) from Association of Energy Engineers
- EMSAGE Laureate Honor, College of Earth & Mineral Sciences, Penn State University